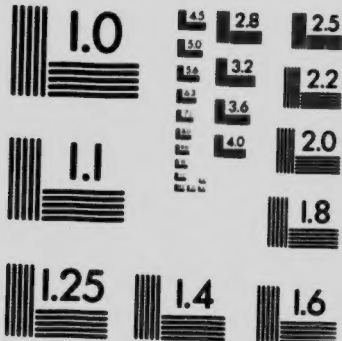


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**Methods and Preliminary Results in the
Spectroscopic Determination of the
Solar Rotation**

BY

J. S. PLASKETT, B.A. F.R.S.C. and R. E. DeLURY, Ph.D.

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Methods and Preliminary Results in the Spectroscopic Determination of the Solar Rotation.

By J. S. PLASKETT, B.A. F.R.S.C. AND R. E. DELURY, Ph.D.

(Read May 17, 1911.)

The determination of the rotation of the sun by the Doppler displacement of the spectral lines at opposite limbs was early placed on the programme of work of the Dominion Observatory; was indeed one of the main investigations planned for the equipment for solar research whose nucleus was the 20-inch coelostat used in the Canadian Eclipse Expedition to Ecuador in 1905. But various causes have delayed the actual making of an effective observation, the principal ones being the delay in the construction of the shelter for the horizontal coelostat telescope and the difficulty of securing a suitable plane grating for the spectrograph. No less than four different gratings have been tested and even the one finally in use it is hoped eventually to replace by a better one.

Before describing the apparatus, it will be of value to give a brief historical sketch of the work already done on this problem. The early work of Vogel in 1871, was of use chiefly in showing the correctness of the Doppler principle and in indicating the possibility of obtaining by more powerful apparatus an accurate value of the solar rotation. Young, in 1876, with a diffraction grating spectroscope measured the displacement of the lines at the sun's equator, showing that the velocity of rotation thereby obtained agreed with that determined from the observation of sunspots. Duner at Upsala, in 1888, began his classical researches upon the solar rotation continued through 1889 and 1890, and repeated in the years 1901 to 1903. His observations made with a grating spectrograph attached to a refractor consisted of visual measures of the displacements of an iron line λ 6301.718 at the sun's limb with respect to a neighboring atmospheric line λ 6302.209. The former is displaced by the solar rotation while the latter, due to absorption in the earth's atmosphere, is stationary. The measures are, therefore, wholly differential, the values obtained were of high accuracy and Duner's methods have formed the basis of more recent investigations. Halm at Edinburgh in 1902 to 1906, using the same lines as Duner, measured visually the solar rotation and obtained results of great accuracy, which seemed to indicate a variability in the rotation rate, one of the important problems to be settled by future investigation.

All the measures above referred to were obtained visually and, although Jewell made some photographic observations at Baltimore, no results were published. The practical inception of the photographic method with its many advantages is due to Adams at Mt. Wilson who, using the Snow and tower telescopes in 1906-7 and in 1908, with stationary spectrographs of high dispersion, obtained results of remarkable accuracy with probable errors several times lower than those of the earlier observations. He used the region in the violet between λ 4200 and λ 4300 with a linear dispersion 0.7 and 0.6 Angstrom to the millimetre. His results indicate that the rotation rate is practically constant, thus differing from Halm. The value obtained from different elements varies slightly seeming to depend upon their height in the reversing layer, and this is particularly shown for the H_{α} line and for Ca 4227, whose rotational velocities are about 3 % greater than that of the general reversing layer.

At the meeting of the International Union for Co-operation in Solar Research, held at Mt. Wilson last August, which one of us had the privilege of attending, a committee consisting of Messrs. Adams, Belopolsky, Dyson, Newall, Plaskett and Schlesinger was appointed, the question was carefully discussed and arrangements made for a combined attack on the various phases of the problem. To this end selected regions of the spectrum, between λ 3600 and λ 6400, were allotted to each member for observation, and in addition a general region, that already used by Adams, between λ 4220 and λ 4280 was chosen for universal observation to serve as a check upon instrumental or personal errors. The region allotted to the Dominion Observatory is from λ 5500- λ 5700, the latitudes to be observed 0° , 15° , 30° , 45° , 60° and 75° , to which are to be added, if possible, the higher latitudes 80° and 85° . In this region, lines are to be selected from as many elements as possible, especially those of high or low atomic weight, in order to throw light upon the question of differences in rotational value for different elements.

A description of the coelostat telescope employed to produce the sun's images examined in the present work, is given in the Report of the Chief Astronomer.¹

This instrument is mounted in a louvred house (part of which may be rolled back to admit the sunlight) which is connected by means of a louvred passage to a tunnel which enters the Solar Research Laboratory on the north side of the Observatory. It consists essentially of a plane silvered mirror twenty inches in diameter mounted

¹ Plaskett, Report of the Chief Astronomer for the year ending March 31, 1909, pp. 207-209.

with its axis pointing to the north pole and driven by clockwork, so that it directs the sun's beams southward to another twenty-inch plane mirror, which in turn reflects the sunlight northward to an eighteen-inch concave mirror. This mirror reflects the light southward into the solar laboratory, focussing the image at about 80 feet. The primary mirror with its clockwork is mounted on an iron truck which may be rolled on iron rails, supported on a cement pier, eastward or westward, so that in the morning it may be moved to one side and in the afternoon to the other side to get more nearly normal reflection. The secondary mirror is mounted so that it may be rolled in a northerly-southerly direction to allow for the seasonal changes in declination of the sun. By rotating and tilting this mirror the sunbeam may be thrown fairly on the concave mirror. The concave mirror may be rolled back and forth to focus the image at any desired place in the laboratory. To this mirror are clamped two arms operated by screws, by turning which the mirror may be tilted in two directions giving motions to the image in vertical and horizontal directions. By means of cables running through pulleys to turning drums¹ in the laboratory, these motions may be given from beside the image so that it may be placed in any desired position, and any "drifting" of the image due to irregularities in the driving of the clock or to atmospheric disturbances may be corrected. A similar device is being installed so that the focus may be altered from a point in the laboratory. The primary mirror is covered by a white window blind, operated by means of a string leading into the laboratory, and used to protect the mirror, when not in use, from the sun's heat which distorts the surfaces of the mirrors, thus spoiling the definition of the image. The latter is seldom perfect on account of the unsteadiness of the atmosphere, but it is not greatly disturbed in the coelostat house on account of the *louvres* (covered with canvas in the winter) which induce circulation thus preventing stratification in the passage.

By means of this telescope the sun's image is thrown on the face of the 23-foot spectrograph, a detailed description of which has already been given along with some results obtained with the first grating tested,² and the measurement of 80 lines on one of the rotation plates made by it. The optical parts of the spectrograph are:—A slit with metal jaws provided with a micrometer, for adjusting its width, reading to thousandths of an inch; a six-inch collimating lens of 22 ft. 10 in. focal length for yellow light; and a plane reflecting grating ruled on speculum metal. The parts are arranged on the "auto-

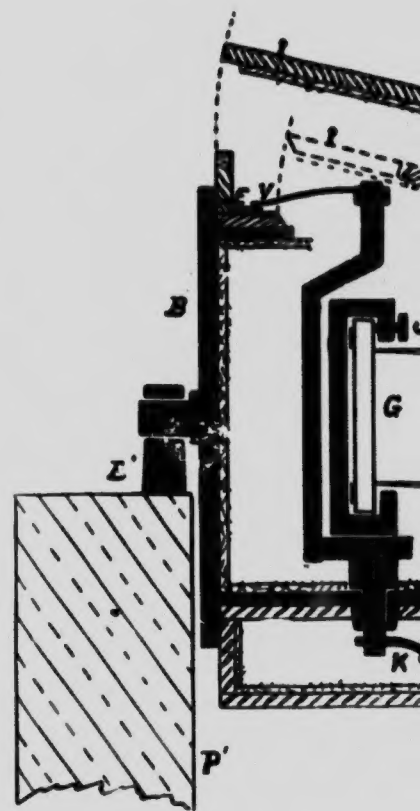
¹ De Lury, *Jour.-Roy.-Astron. Soc.*, Can. V. 33-35.

² De Lury, Report of the Chief Astronomer for the year ending Mar. 31, 1909, pp. 251-256.

collimating" plan of O. Von Littrow. The slit is placed at (or near) the focus of the lens, and the grating is placed on the other side of the lens in such a manner that the light returning through the lens is focussed just below the slit, as illustrated in Fig. 1, which represents a vertical section through the middle of the spectrograph and mountings. *S* is the slit, *L* the lens placed about 23 ft. from the slit and *G* is the grating placed just behind the lens *L* and adjusted so that its ruled lines are parallel to the slit. The beam of light to be examined passes through *S* spreading out to fill *L*, which renders it parallel before it reaches *G*, which is tilted to direct light back through the lens so that the latter focusses it below the slit. Here it may be examined with an eye-piece or photographed in the plate-holder *C*. The forward tilt of the grating is given by the screw *J* in the grating cell and suitable springs pressing against the back of the grating. The grating in its cell rests on the stand *G'*, which revolves in a cylindrical socket in the bottom of the cast iron end, *B*, of the spectrograph, and, by turning a handle *H'* attached to a worm working in a toothed sector, *K*, which is clamped rigidly to the spindle *G'*, the grating may be rotated about an axis passing through its surface, thus diffracting any desired part of the spectrum of any order through the lens to *C*. By means of the vernier-pointer, *V*, readings to tenths of a degree may be made on the graduated arc, *E*, and a record of these readings with the corresponding wave-lengths is kept, so that by turning *H'*, any desired wave-lengths may be at once directed to the centre of *C*, and the grating is then clamped in this position. The lens may be shifted and clamped to any focus by means of the handle *H*, and the position of the pointer, *F*, is read on a millimetre scale attached to the bottom of *B*.

The plate-holder, made to take 2.5 in. $\times$ 12 in. plates is clamped in the frame *C'*, which may be raised or lowered by rack and pinion, so that several strips of spectra may be put side by side on the same plate and spaced as desired by reference to a millimetre scale.

In addition to these motions of the parts, the spectrograph, as a whole, may be rotated about its axis¹ thus facilitating the study of the rotation of the sun by enabling the observer to reflect (by means of a suitable system of reflecting prisms such as described later) the limbs of the sun at opposite ends of any diameter, so that they are always tangential to the slit. In Fig. 1, *A* and *B* are the ends resting on the bearings *A'* and *B'*, which are supported by the cement piers *P*, *P'*, built on the cement floor. The end, *A*, is of half-inch cast brass. It has a V-groove running around its circular rim into which the semi-circular cast-iron support *A'* is bevelled to fit. The back of *A* is a rectangular



¹Plaskett, Report of Chief Astronomer, 1907, p. 58.

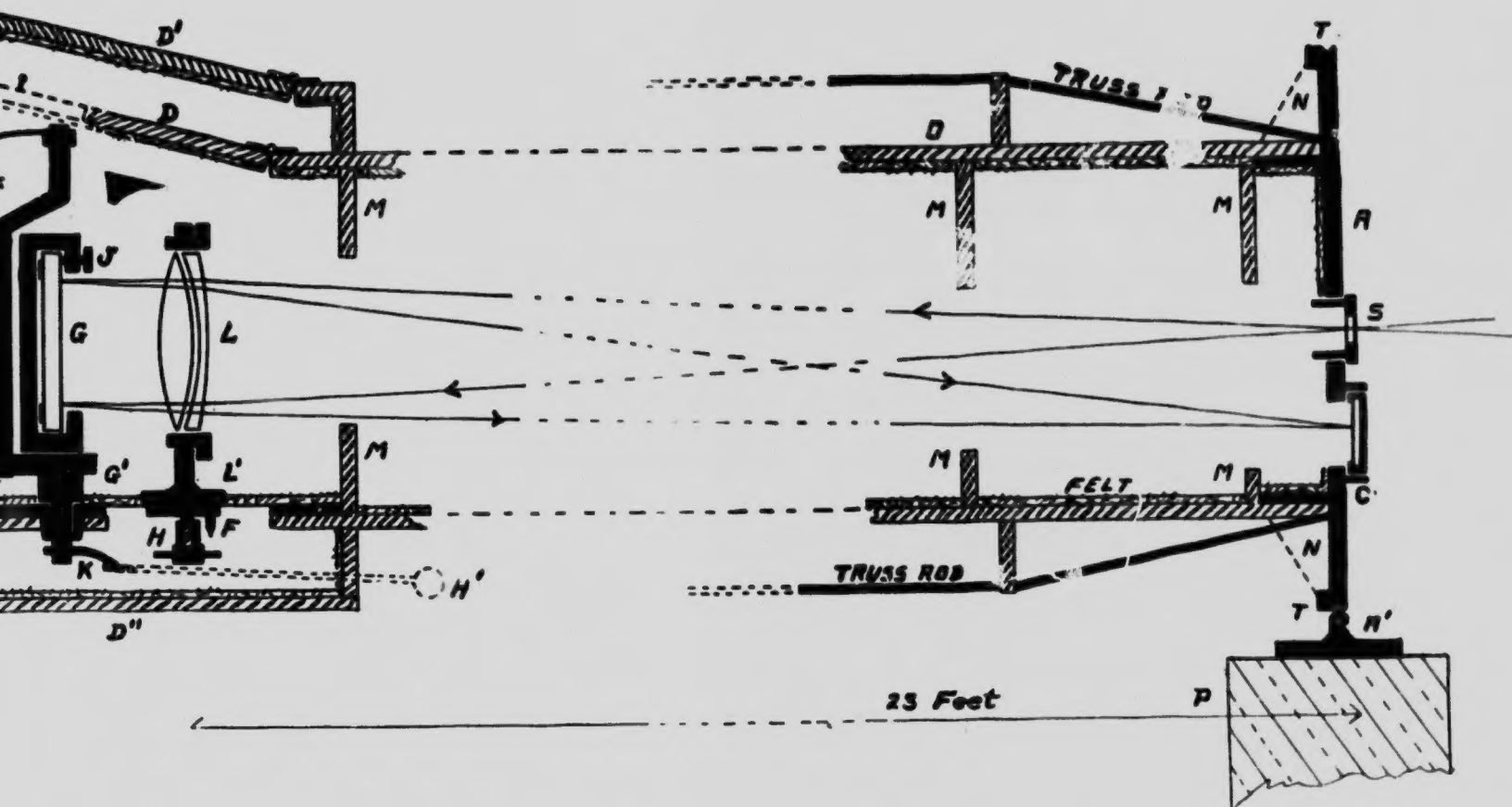


FIG. 1.



rim 3 in. $\times$ 11 in. $\times$ 14 in. over which the wooden box O is tightly screwed and clamped. The axle of B, which is of cast-iron works in the cylindrical brass bearing B'. The sides of B project 3 in. on the top and 16 in. on the sides and bottom, the latter being milled smooth to give easy bearings for the grating and lens mountings.

The rim of A is toothed and into these teeth fits a gear attached to the support A'; by turning this gear the spectrograph may be rotated. The circular face of A is graduated in degrees and by means of a vernier attached to A', the angle may be read to tenths of a degree. This is necessary in determining the "East and West" line by allowing the image of the sun to drift across the face A tangentially to some arbitrary line on A. From this angle read on the vernier, the position of the sun's disc, which lies in the plane of the sun's equator, is easily found since the inclination of these two lines to each other at any time is known, and hence the arbitrary line on A may be made parallel to any required diameter of the sun's image.

The wooden box O, which is strengthened by truss rods, is painted black on the inside and is provided with diaphragms, M, to prevent as much as possible the diffused light reflected from the lens and grating from striking the photographic plate in the holder, C. There is a hinged door just above the grating and lens, so that these may be conveniently reached.

The box, O, is lined with felt to prevent sudden changes of temperature, and the end B is doubly boxed in order to prevent convection currents from passing in front of the grating and destroying the definition. Doors D' and D'' are placed in the outer box.

The system of reflecting prisms used for reflecting the light from opposite ends of a diameter of the disc through to the slit (as mentioned above), is arranged as shown in Fig. 2. The prisms A, A' and B, B' are mounted on brass holders on a solid casting which holds at its centre the slit with its adjusting micrometer and closing shutter, the whole being mounted on the face of the spectrograph. Light from one limb of the sun enters the reflecting prism A and is reflected through A', which in turn reflects the light through slit, S. In a similar manner, B reflects the light from the opposite limb through B', and this prism directs it through the slit. A' is notched as shown in the upper part of Fig. 2 to receive the end of B'. In this way two beams of light are reflected to the grating through B' with a beam from A' placed midway between them and, consequently 3 strips of spectra are diffracted back to C as shown in Fig. 3. By means of a small three-tongued mask the widths of these strips and the spacing are kept constant for purposes of measuring. The prisms are adjusted to give even illumination of the grating

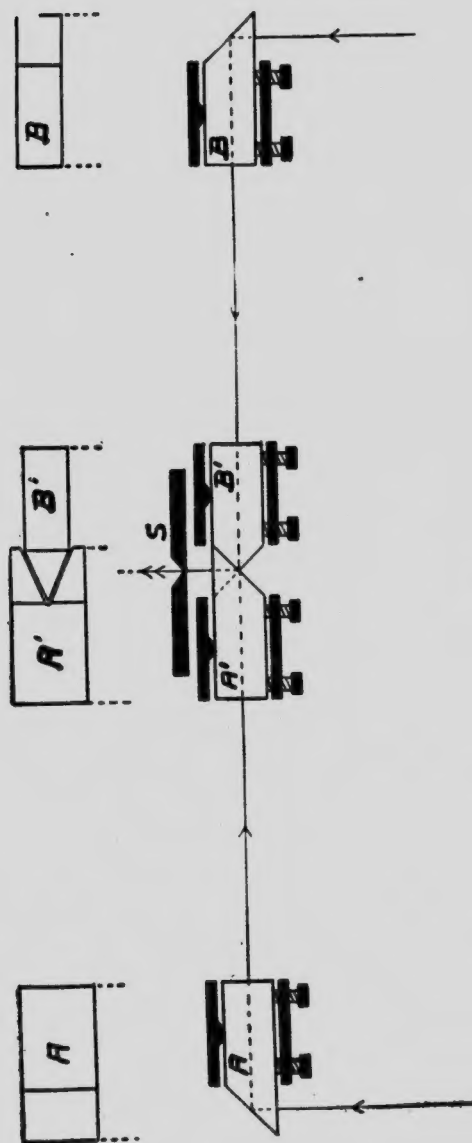


FIG. 2.

by means of the screws shown in Fig. 2 and the rounded projection back of the prisms on which they rock.

The notched prism B' is much more easily adjusted than the two prisms formerly employed for the same purpose. The idea of placing the two strips of spectra from one limb on each side of the strip from the other limb by means of the notched prism, we believe to be a new and important point, as it eliminates certain small errors of measurement which may occur in the method of having just two strips side by side, which has been employed by other investigators in this field.

Over these prisms is placed a brass plate serving to protect them from dust and injury and also providing means of guiding the sun's image centrally. This is done by aid of a circle of diameter 229 mm., slightly greater than the greatest diameter of the sun's disc. In this circle are two little adjustable windows through which light from any desired parts, on or within the limb, may be admitted to the reflecting prisms. Under these windows are little cups to receive suitable filters when it is necessary to use such. The diameter of the circle which passes centrally through these windows is ruled on the plate, and parallel to this a tangent is ruled to the circle for determining the "East and West" line as mentioned above. To take a rotation plate, the sun's image—so focused that after passing through the prisms it comes to a focus at the slit—is guided centrally in the circle, and the ruled diameter is set at any desired inclination to the sun's equator.

As already stated, it was decided in 1906, to make the determination of the Solar rotation one of the main researches for the coelostat telescope then designed. The shelter for this telescope was not completed until the summer of 1908, and the completion of the solar spectrograph was delayed until a somewhat later date. The plane grating used in this instrument was one of Michelson's early attempts, having a ruled surface about 5 by 4½ inches with 500 lines to the millimetre. Tests of this soon showed that the definition given was poor and that the grating had some curious focal properties.¹ Preliminary measures of some rotation plates made with this grating showed, owing to the diffuse nature of the lines, high probable errors and it was felt that satisfactory results were impossible.² It was not until the spring of 1910 that a new grating, No. 55, ruled specially for this work, by Prof. Michelson was obtained. This had a ruled surface of 5 × 5½ inches with 700 lines to the millimetre and gave very bright spectra with good definition. The astigmatism present was shown to be due to the lines of the ruling not being quite straight, and was entirely removed when about two-

¹ De Lury, Jour. Roy. Astron. Soc., Can. V. 26-32.

² De Lury, Report of the Chief Astronomer, 1909, 251-256.

fifths of their length was occulted. The definition was improved by masking one end of the ruling to the extent of two inches, so that the ruled surface in use was reduced to about $2\frac{1}{2} \times 3\frac{1}{2}$ inches. Even with this reduction in surface the spectra were so bright as only to require comparatively short exposures in the 2nd and 3rd orders. The principal difficulty remaining seemed to be a certain amount of diffused light which blocked up the lines, diminishing the contrast, and increasing the difficulty and probable error of measurement.

Michelson very generously offered to furnish a new grating on account of these defects, and in the autumn of 1910, we received grating No. 43 with a ruled surface $6\frac{1}{2} \times 2\frac{1}{4}$ inches having about 580 lines to the millimetre. This was the grating used by Gale and Lemon in their investigation on the mercury lines and the one used by Michelson in his laboratory, and is undoubtedly a very fine instrument. But a test showed that, for the purpose required in this work, its smaller dispersion and lower brightness rendered it not so suitable as the former, which was consequently retained.

Within the last month or so a plane grating, ruled by Anderson at Johns Hopkins, has been received and tested. This grating has a ruled surface $3\frac{1}{2} \times 5$ inches with 15,000 lines to the inch. This grating gives definition of about the same quality as the Michelson grating with freedom from diffused light, so that there is considerable more contrast between the lines and continuous spectrum and consequently greater ease and accuracy of measurement. Unfortunately, there is also astigmatism present, which is only satisfactorily removed when about three-fifths of the length of the lines is occulted. However, the whole width of the ruling can be utilized and it gives good resolving power, and is fairly bright in the third order.

A large number of experimental and test plates have been made with these four gratings to determine the conditions under which the best results can be obtained. Considerable experimentation with different makes and brands of plates has also been undertaken to determine the most suitable emulsion. The Seed Contrast Process seems the best for the work at λ 4250, while the Cramer Iso. Process has been selected for the region λ 5600. A trial was made of the Seed Process stained with Erythrosin for work in the latter region, but although they are of somewhat finer grain than the Cramer, the trouble of staining, the poor keeping qualities, and the lack of uniformity in successive batches led to the choice of the commercially prepared orthochromatic plates.

In the determination of the solar rotation by the measurements of line displacements at opposite limbs, the three most important and interesting points to be settled are:—

1. The actual velocity of rotation at the different latitudes with the law connecting the change of angular velocity with the latitude
2. Whether the rotational velocity of the sun is constant.
3. Whether the velocity obtained from different elements, say those at higher or lower levels in the solar atmosphere, is constant.

For the adequate discussion of the first two problems a long extended series of investigations is necessary, and they naturally can not be touched upon here. The third question also requires much more observational material than we now have, before any definite statement can be made. Adams' results show that there are considerable differences in the values given by different elements. The lines of carbon and lanthanum, presumably at a lower level, give lower rotational velocities than the general reversing layer, one line of manganese gives a higher value, and the blue line of calcium λ 4227 and H_{α} give much higher values. Schlesinger, on the contrary, in a preliminary paper given at the last meeting of the Astronomical Astrophysical Society and of America, states that any differences he obtained in the reversing layer were not greater than and not distinguishable from the accidental errors of measurement.

It seemed desirable to us therefore to test this matter, and acting on the supposition that the small differences obtained by Adams might be due to subjective errors in measurement caused by the character of the lines themselves and not to an actual shift due to different velocities, a scheme was devised for testing this supposition. A special slit was made with an attachment in the centre of the jaws, which displaced transversely to any desired distance a strip about a millimetre long. It is evident that, by placing a suitable diaphragm over this attachment to limit the widths of the spectrum obtained, one can produce three strips of spectra of the same width and separated by the same distance as those made by the reflecting prism arrangement, and, moreover, the lines of the centre strip may be displaced any desired distance to the red or violet of the lines of the outside strips, giving the same effect and appearance as rotation spectra, except that the displacement of the lines is arbitrary and exactly the same for each. A series of plates were made with this broken slit at the region λ 4200-4300, the same region as used by Adams and chosen as the general region for universal observation by the Rotation Committee of the Solar Union. These spectra were made by setting the sun on the slit attachment at the same distance within the limb as the rotation spectra are obtained. We will then have evidently spectra exactly identical in appearance with rotation spectra, measurable in exactly the same way, but with a displacement that we know must be the same for each line. Twelve of these spectra were measured by each of us, the lines measured

15 in all, being given in the tables of displacements following. From the 4th to the 13th inclusive, are the lines selected for measurement by the Rotation Committee; the first three and the last two are lines used by Adams, which are of interest on account of giving a different velocity value from the general reversing layer. The measurements were all made on a special Toepfer measuring engine having a micrometer screw of 0.5 mm. pitch, and 300 mm. long. The head reads directly to thousandths and by estimation to ten thousandths of a millimetre. The plates were measured in the usual way by making 4 settings on the central strip, and 2 each on top and bottom strips. The difference of the means is the displacement. When the measure is completed the plate is reversed on the carriage and remeasured as before. Thus each displacement is the mean of 8 settings. There is some indication of a slight systematic difference in the displacements obtained in the two positions of the plate, sufficient to indicate the desirability of measuring both ways. In any case the lines frequently have a different appearance on reversal and no doubt a much more accurate value of the displacement is obtained. The displacements and probable errors in the following tables are given in ten thousandths of a millimetre.

DISPLACEMENTS.

(Measured by Plaskett.)

Line	Plate No. 699.						Plate No. 701.					
	a	b	c	d	e	f	a	b	c	d	e	f
4196-699	683	692	710	704	709	706	693	717	683	693	711	704
4197-257	706	716	714	705	719	700	717	702	715	696	681	699
4216-136	688	710	689	696	706	702	704	709	699	689	703	705
4220-509	686	693	705	688	695	704	710	694	692	696	706	709
4225-619	703	688	700	686	705	704	696	708	710	696	683	699
4232-887	689	677	695	704	684	696	715	707	703	689	705	695
4241-285	692	708	704	696	691	710	710	711	707	702	689	716
4246-996	689	675	693	682	695	700	707	699	701	685	687	689
4257-815		675	693	675	717	708	713	711	713	700	698	698
4258-477		704	697	691	691	703	715	705	716	689	685	701
4266-081	679		721	682	707	712	698	706	721	700	687	689
4268-915	681	704	698	682	717	707	712	711	708	696	696	710
4276-836	691	691	708	684	700	686	711	705	698	702	712	709
4290-377	699	686	705	699	706	696	703	695	713	693	709	704
4291-630	700	681	695	686	715	710	713	709	711	684	706	700
Mean Disp.	692	693	702	691	704	703	708	706	706	694	697	702
P. E. Single Line	9.1	6.0	6.4	7.2	4.6	5.0	4.2	6.8	3.9	7.4	5.0	5.6

Average probable error single line..... $\pm$.00059 mm." " " plate..... $\pm$.00016 "" displacement..... $\pm$.0700 "Probable error displacement, single plate..... $\pm$.00041 "

DISPLACEMENTS.
(Measured by DeLury.)

Line.	Plate No. 699.						Plate No. 701.					
	a	b	c	d	e	f	a	b	c	d	e	f
4196-699	647	688	704	718	691	708	624	704	640	721	699	717
4197-257	634	798	708	697	707	682	616	701	616	772	675	603
4216-136	701	686	702	695	721	741	696	686	720	682	714	715
4220-509	632	725	744	705	688	685	745	726	690	654	687	700
4225-619	735	632	752	639	679	727	673	782	737	723	723	733
4232-887	682	692	743	675	678	635	679	725	700	719	688	665
4241-285	688	658	633	733	727	808	736	651	715	751	664	650
4246-996	639	644	710	676	709	754	654	656	726	704	664	687
4257-815	693	599	650	685	677	736	690	763	722	641	702	772
4258-477	692	673	702	683	688	698	703	673	706	675	688	688
4266-081	638	717	676	704	676	673	675	616	759	724	666	645
4268-915	589	689	649	694	673	695	659	703	649	667	700	631
4276-836	715	670	634	724	702	692	747	700	730	687	662	686
4290-377	744	785	708	697	691	678	743	737	714	735	730	678
4291-630	747	664	667	711	700	688	717	661	701	636	692	724
Mean Vely	678	686	696	696	694	707	690	699	702	699	699	686
P. E. Single Line	31.6	33.1	29.2	15.5	11.3	27.9	29.5	29.7	26.5	27.2	14.8	29.3

Average probable error Single Line + .00255 mm.
 " " " Plate + .00065 "
 " Displacement + .0694 "
 Probable error displacement single plate + .00080 "

MEAN DISPLACEMENTS OF LINES.

Line.	Element.	Intensity.	Quality.	Plaskett.		DeLury.	
				Mean Disp.	Prob. Error.	Mean Disp.	Prob. Error.
4196-599	La	2	Diffuse	0.700	+ .00076	.0694	+ .00267
4197-257	C	2	Asymm'l	706	84	684	427
4216-136	C	2	"	700	52	705	146
4220-509	Fe	3	Good	698	50	698	239
4225-619	Fe	3	"	698	48	711	340
4232-887	Fe	2	Narrow	697	68	692	197
4241-285	Fe-Zr	2	"	703	58	701	344
4246-996	Sc	5	Very broad	692	64	678	227
4257-815	Mn	2	Diffuse	700	67	694	346
4258-477	Fe	2	Broad	699	51	689	97
4266-081	Mn	2	Fair	701	73	681	278
4268-915	Fe	2	Good	702	51	667	290
4276-836	Zr	2	Diffuse	700	58	695	228
4290-377	Ti	1	Broad	700	48	717	281
4291-630	Fe	2	"	701	54	692	255

In discussing these measures and probable errors it will be noted that the probable error of one observer is considerably the greater, this being probably due to less experience in spectrum measurements. Considerable more weight should be given to the results with the lower probable error.

In the first place, the mean displacement given by the measures of all lines on all plates is practically the same for the two observers, the difference being too small to be systematic. In this connection it may be worth noting that measures of lines 4, 5, 6, 7, 8, probably the five best lines in the fifteen, on one of the plates by 6 observers showed considerable differences in the mean displacements, there being a difference of about $\cdot 003$ mm. between the highest $\cdot 0707$ mm. and lowest $\cdot 0674$ mm. The trend of the measures seemed to indicate that the greater the experience of the measurer the higher the measured displacement. It is difficult to assign any reason for such apparently systematic differences, and although not sufficient data are at present available, it is evident that some attention must be bestowed upon this phase of the question. Such a difference in the measures of a rotation plate would correspond to a difference of about 3% in the value of the rotation at the equator.

In the second place, considering the differences in displacements given by different lines, they appear to be on the whole accidental in character, though, in the case of Plaskett's measures, there are at least two lines, C 4197.257 and Sc 4246.996, one asymmetrical and the other very broad, showing systematic deviations from the mean greater than attributable to accidental error. There are even greater differences in De Lury's values, but owing to his larger probable error they can not probably be definitely assumed to be systematic in character.

There is thus seen to be a possibility that the character of the lines themselves may lead to differences in the measured displacement, of about the same amount as those found by Adams in the rotation values. It is questionable whether the differences here found are sufficient to account for all the discrepancies found by Adams, as they do not apply to all the lines, and the question can only be definitely settled by the employment of much more material, such as that to be secured by the committee, than is at present available.

The probable errors of measurement of an average line by Plaskett is $\pm \cdot 0006$ mm., equivalent with the dispersion used to $\pm \cdot 013$ km. in the rotation value, which is of about the same order as those obtained by Adams.

It is only necessary to say a few words in this paper about the procedure followed in making the rotation plates, as that will be discussed at greater length in a future paper when definite results will be

published. There are four essential precautions necessary in obtaining accurate values of the solar rotation.

1. The emulsion on the photographic plate must be exactly in the focus of the spectrum.

2. The illumination of the grating from the opposite limbs of the sun must be similar and uniform.

3. The solar definition must be good, and the sky free from haze.

4. Care must be taken that the reflecting prisms receive light from the latitudes desired.

1 and 2 above, conditions inside the spectrograph, are essential in preventing spurious displacements of the spectrum lines producing systematic errors in the rotation values. If either condition is exactly fulfilled the other is not so essential, but as it is impossible either to keep the plate at the *exact* focus or to have *absolutely* equal and uniform illumination from the two limbs, the only safe procedure is to fulfill both conditions as closely as possible. The focus may be determined either by the definition test or preferably by the Hartmann method of extra-focal exposures.

It has been found here that in the region around λ 5600 the focal surface is neither exactly normal to the axis nor is it a plane. The normal to the surface is inclined about 1° to the normal to the axis, and the focus is about 2.5 mm. longer at the centre than at the ends of a plate 30 cm. long. Consequently the plates are bent to the proper curvature and inclined at the proper angle, so that the whole length of spectrum may be in focus. The equality of illumination is tested by opening the slit sufficiently wide to see, through the door at the rear of the spectrograph, the circle of light thrown on the collimator by the concave mirror. In this way the prisms can be so adjusted that the two images are superposed and uniform illumination much more closely obtained than when one observes with a slit of normal width the grating surface from the position of the plate.

3 and 4 are essential conditions outside the spectrograph. The former is maintained by exposing the mirrors to the sun only during the actual exposures, and shading them for a sufficiently long interval between exposures to allow them to return to their normal state. The latter is arranged by careful determination, first, of the exact position on the outer plate at which the light is incident, which passes through the slit from each limb, and second, that this position is exactly placed on the desired latitude. The position angle is obtained, by the aid of tables of the position angle of the sun's axis, from the East and West line, determined by stopping the coelostat clock and allowing the sun's image to drift across the face of the spectrograph, as mentioned above.

We do not propose in this paper to publish any definitive values of the solar rotation, they will be withheld until a series has been obtained and measured. It may be of interest, however, to present a few measures of some of the experimental plates obtained which will give an idea of the relative accuracy attainable.

The measures given in the following table are of plates at 0° latitude obtained nearly a year ago, shortly after grating No. 55 was received. They were taken in the second order of this grating about the region λ 4500, which was used before the definite allotment of regions at the Solar Union. The linear dispersion here is about 1.02 Angstroms to the millimetre, considerably less than used by Adams. However, the definition in the 2nd order was so much better than that in the 3rd at this region as to more than compensate for the diminished dispersion. 29 lines were measured on each plate by Plaskett with the result shown below.

MEASURES OF TEST PLATES.

	528 a		531 a		531 b		566 a		566 b	
	Disp.	Vel.	Disp.	Vel.	Disp.	Vel.	Disp.	Vel.	Disp.	Vel.
4432.736	-0569	1.882	-0570	1.885	-0573	1.895	-0556	1.839	-0573	1.893
4435.321	559	848	572	890	574	897	557	840	555	834
4438.570	569	880	573	892	570	882	552	823	563	859
4445.641	562	852	559	843	567	869	548	807	557	836
4454.552	557	832	565	858	563	852	543	786	556	829
4464.617	571	873	575	886	577	892	562	843	553	814
4468.663	571	870	564	848	573	877	564	847	567	857
4484.392	578	882	570	858	566	846	568	852	570	858
4489.911	581	892	570	857	572	863	553	801	565	841
4502.388	580	882	576	869	575	866	554	798	553	795
4508.455	588	905	571	850	574	860	568	841	566	834
4512.906	570	846	569	843	584	891	573	855	560	813
4518.198	585	890	580	874	586	894	566	830	572	849
4523.572	585	888	597	926	587	894	576	858	572	846
4527.401	571	841	584	883	584	876	565	822	569	835
4531.801	573	845	583	877	581	871	561	806	558	796
4534.903	580	866	592	905	584	879	580	866	572	840
4546.429	579	857	579	857	571	832	575	844	571	832
4548.938	585	875	591	894	590	891	564	808	574	840
4554.211	576	843	582	862	591	891	572	830	577	846
4555.662	574	837	582	862	586	875	571	827	569	821
4558.827	589	883	579	851	576	841	576	841	572	829
4563.939	587	873	585	867	575	835	567	810	577	841
4571.275	586	867	585	864	575	832	572	822	570	816
4572.156	589	875	587	869	594	891	573	825	578	840
4578.732	578	838	586	863	591	879	575	829	570	812
4590.126	577	829	576	826	597	892	580	838	574	819
4602.183	597	886	589	861	593	874	564	792	579	829
4603.126	593	873	579	829	582	839	576	820	571	804
Mean velocity	1.866		1.868		1.872		1.828		1.834	
Probable error										
line	+ .014		+ .015		+ .015		+ .013		+ .015	
Corrected velocities	2.055		2.056		2.060		2.012		2.018	

There is fair agreement between the values of the rotation, although the two last are lower than they should be. This is probably due to the uneven illumination of the collimator and grating from the two limbs of the sun as the plates were made before the best methods of adjustment had been developed, and before the necessity of the greatest care in adjustment had been recognized.

The agreement between the values for the different lines is good, corresponding to a probable error of linear measurement of less than a micron. This, however, was only attained by the greatest care and after considerable experience in measuring these rotation plates.

It gives us great pleasure to acknowledge the readiness of the Director, Dr. W. F. King, to supply all the needed apparatus, and the encouragement he has given in the prosecution of the work.

Dominion Observatory,
Ottawa,
June, 1911.

LINES SELECTED FOR MEASUREMENT

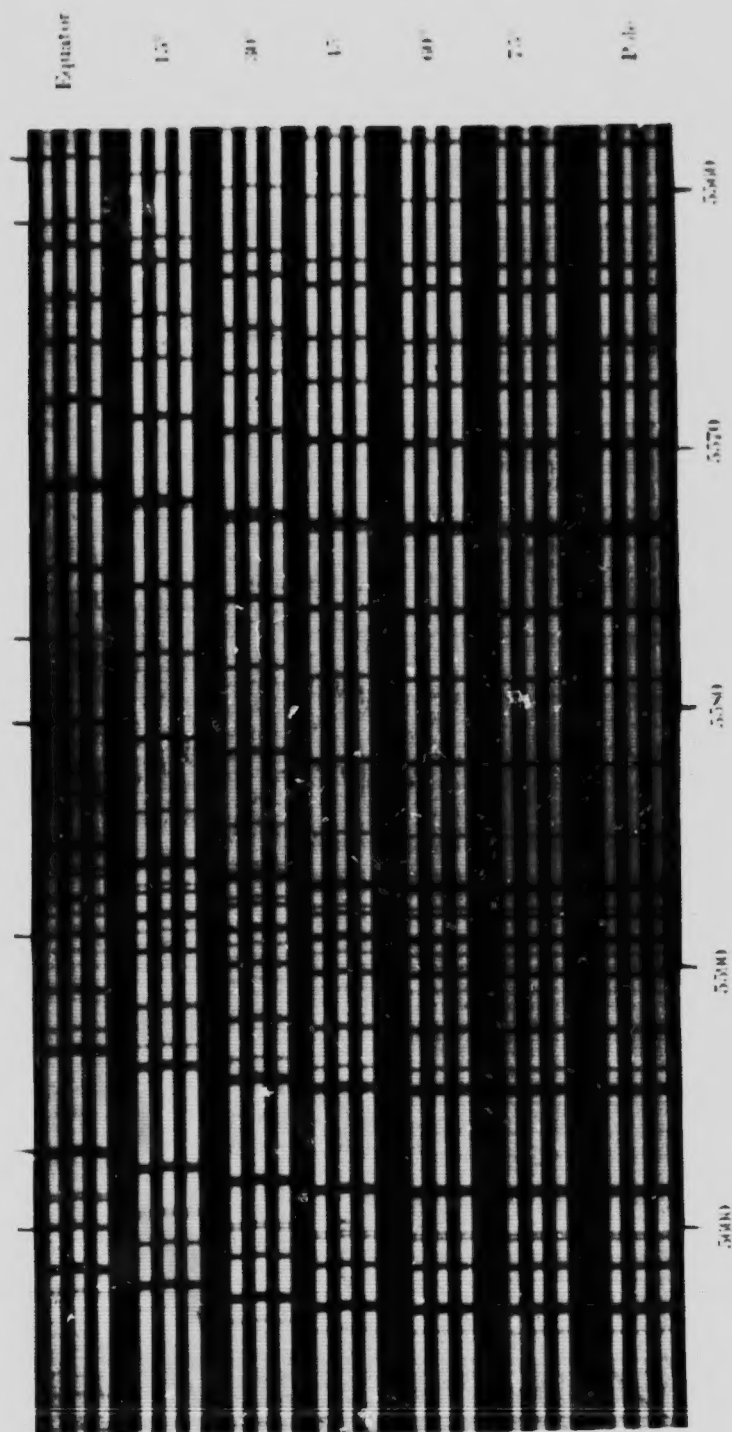


Fig. 3. Portion of Rotation Plate enlarged about 2.5 times